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LATEST DYNAMO-ELECTRIC MACHINES.

A SUPPLEMENT

TO

DYNAMO-ELECTRIC MACHINERY

BY

PROFESSOR SILVANUS P. THOMPSON,

D.Sc., B.A., F.R.S., M.I.E.E.

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LATEST DYNAMO-ELECTRIC MACHINES.

A SUPPLEMENT
TO THE SIXTH EDITION OF
DYNAMO-ELECTRIC MACHINERY.

BY

Phillips

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PREFACE.

In preparing for the press in America this edition, the author desires to express his gratitude to American readers for the appreciation with which the former editions of his work on Dynamo-Electric Machinery have been received at their hands. If he has not always been able to do as full justice to American patterns of machines and American improvements as to those developed in Europe, this defect has occurred from causes over which he had little control, and he willingly acknowledges the importance of the contributions made to progress in this and every branch of the electrical industry by American engineers.

In view of the attempts made in the States to circulate unauthorized copies of his work, he wishes it to be understood as widely as possible that he is responsible for the correctness of those editions only which are published by Messrs. E. & F. N. Spon, Ltd., London, and by Messrs. Spon & Chamberlain, New York. American students of electric engineering will do well to avoid reprints of older editions emanating without authority from other publishers, and for the accuracy of which the author hereby disclaims all responsibility.

American engineers and manufacturers of dynamos and motors are invited to send, from time to time, information of their newest improvements to the author, in order that in future editions he may be able to keep his work as thoroughly as is possible up to date.

SILVANUS P. THOMPSON.

London, January, 1897.

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See list of Illustrations and pages 8 and 10, the words Walker Manufacturing Company should read the Walker Company.

LATEST DYNAMO-ELECTRIC MACHINES.

CHAPTER I.

CONTINUOUS-CURRENT DYNAMOS AND MOTORS.

No very great changes have been made during the last two or three years in the designs of continuous-current machines. There has been a certain amount of dissatisfaction at the disproportionality of the framework and field-magnet of a dynamo and the relatively small armature. It is also felt that the mere accessories ought not to take up such a large proportion of the cost, for in the ideal case the real working part is the armature, and all the rest ought to be but a small additional cost. Notions of this kind, together with the desire to fix the field winding in as close proximity as possible to the armature, has led in the design of bipolar machines to a variety of forms for field-magnet and framework which are somewhat more compact than the ordinary "over" or "under" types (see pages 327 and 403*). The "ironclad" type of field-magnet is finding favor with so many designers, that it is worth while to illustrate some of the existing forms, and to discuss their advantages.

So far as British manufacturers are concerned, this tendency has been accentuated by the demands of the Admiralty that dynamos for use on shipboard should be so designed as not to produce any stray magnetic field which can affect the ship's compasses. To attain this as nearly

* *Dynamo-Electric Machinery.*—Thompson.

as may be, the two poles of a bipolar dynamo are generally set vertically above and below the armature instead of being placed right and left of it. The magnetic circuit is completed by an external yoke of cast steel, which nearly or completely encloses the magnet coils and armature, being in the form of a vertical cylinder, a type which originated with Mr. Mordey. Even this device, which adds greatly to the gross weight of the machine, does not absolutely do away with the existence of a stray field. Ship dynamos of this type have been manufac-

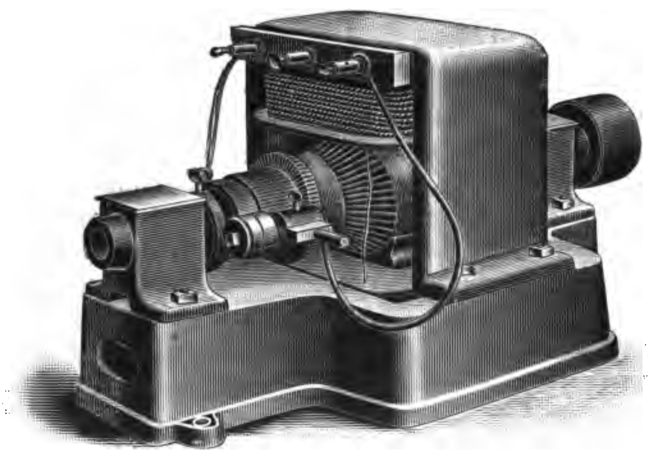


FIG. 521.—IRON-CLAD TYPE OF THE HOBART ELECTRIC MANUFACTURING CO.

tured for some years by Messrs. Mather & Platt, and also by the Silvertown Company.

In the United States a similar tendency has shown itself. Fig. 521 shows a design of the Hobart Electric Manufacturing Company of Troy, O., in which good use is made of the waste space in the bed-plate by filling it with one of the magnet windings, and completing the magnetic circuit through comparatively thin limbs of cast steel of high permeability. It will be observed that if these return paths were wound instead of the pole pieces, the design would resemble that of the McTighe or of the "Manchester" dynamo; but the newer design has

two points of advantage over the latter type. In the first place, the magnetomotive forces of the two coils are in series instead of being in parallel, thus making considerable saving in copper for the same loss in the field (page 150*). Secondly, the magnet windings being close to the air-gap, there is not the same facility for magnetic leakage. (Compare the case of the Lahmeyer type, page 154*.) All the accessories of this dynamo are of the simplest

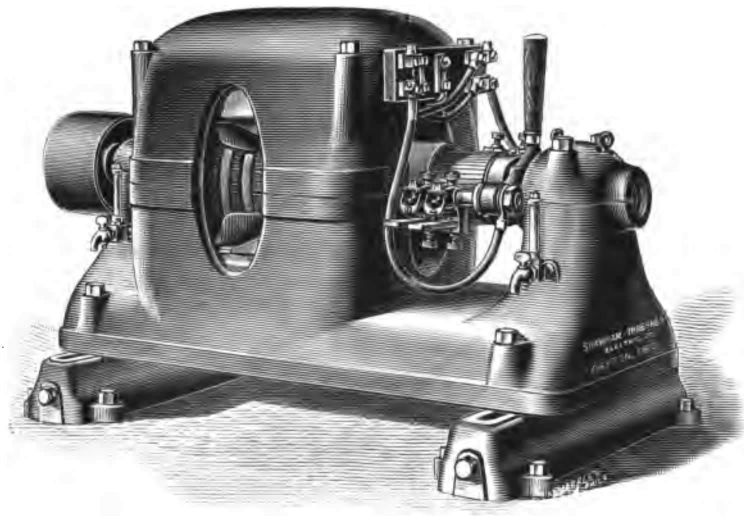


FIG. 522.—IRON-CLAD DYNAMO OF THE THRESHER ELECTRIC CO.

possible design, and by lessening the height of the armature great solidity is given to the bearings.

Fig. 522 shows a machine of the Thresher Electric Company, of Dayton, O., in which the same features are present, but here an opening has been made in the return path for the purpose of ventilation, and the iron is carried round so as more nearly to envelop the ends of the armature. Other instances of iron-clad dynamos of analogous construction will be found in the machines of Messrs. L. W. Davies & Co., and in those of the Triumph Electric Company of Cincinnati.

* *Dynamo-Electric Machinery.*—Thompson.

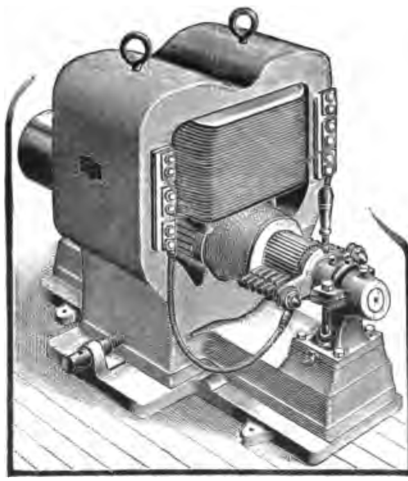


FIG. 523.—IRON-CLAD DYNAMO OF THE LAFAYETTE ENGINEERING AND ELECTRIC WORKS.

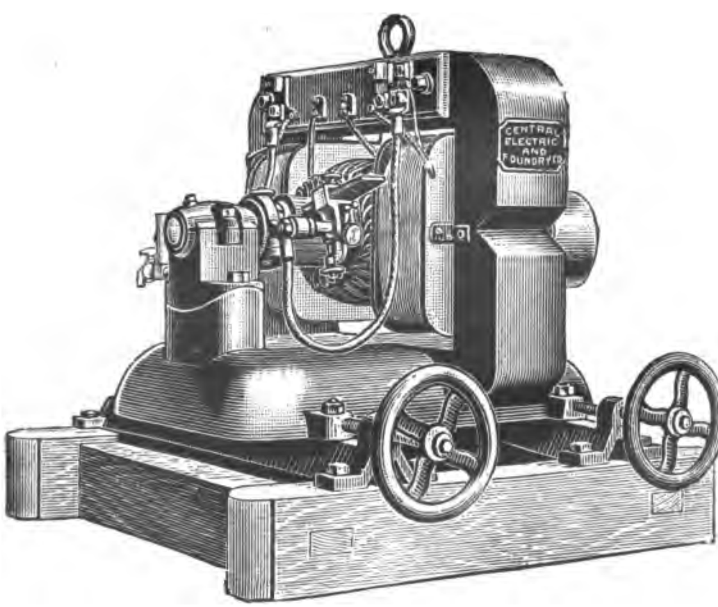


FIG 524.—DYNAMO OF THE CENTRAL ELECTRIC AND FOUNDRY CO.

It may be asked whether it is preferable to have two field coils, as in these machines, or to have one field coil,

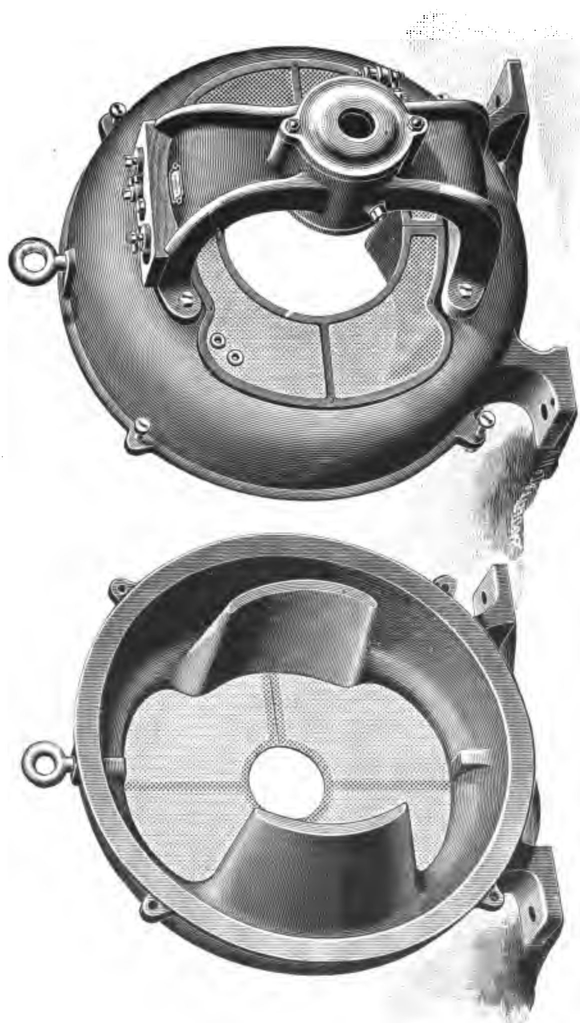


Fig. 525.—Field-Magnet Halves, Lundell Dynamo, for Pole Type.

as in the design of the Lafayette Engineering and Electric Works, Lafayette, Ind., as shown in Fig. 523. The answer to the query is that while one coil simplifies the

construction, two coils create a more symmetrical distribution of the field, and decidedly lessen the tendency

FIG. 526.—MAGNETIZING COIL OF THE LUNDELL DYNAMO.

to magnetic leakage; for each may be considered as expending its own magnetizing force upon its own neighboring half of the armature and on the adjacent air-gap,

FIG. 527.—ARMATURE OF THE LUNDELL DYNAMO.

so that the leakage from the side of the armature to the return path or flanking yoke of iron is but small.

In some cases the coils are placed at the sides of the armature instead of at the top and bottom. This is the case with the machine of the Central Electric and Foundry Company of Lewisburg, Pa., shown in Fig. 524. A machine of the same type is made by the Crescent Electric Machine Company of Brooklyn.

FIG. 528.—ROCKER AND BRUSH-HOLDERS OF THE LUNDELL DYNAMO.

A unique form of field-magnet of a type originated by Mr. Rankine Kennedy some years ago, is that of the Lundell dynamo, shown in its two halves in Fig. 525. The magnetizing coil, shown separately in Fig. 526, is slipped over the internally projecting pôle pieces and entirely encased in the steel casings when these are brought together. It will be seen that the magnetomotive force of this coil is in a direction parallel to the axis of the

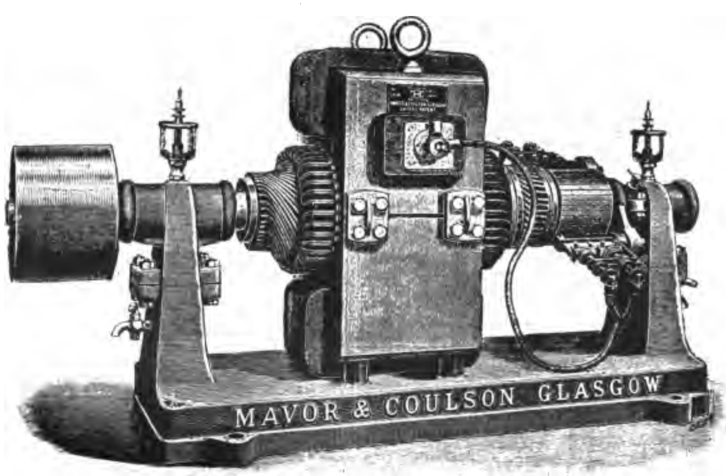


FIG 529.—SAYERS'S DYNAMO.

armature, but the shape of the iron parts causes the greater part of the flux to enter the armature at the sides

and leave it at the top and bottom, thus creating a four-pole field. Although only one magnetizing coil is used to magnetize the four-pole pieces, the fact that it must

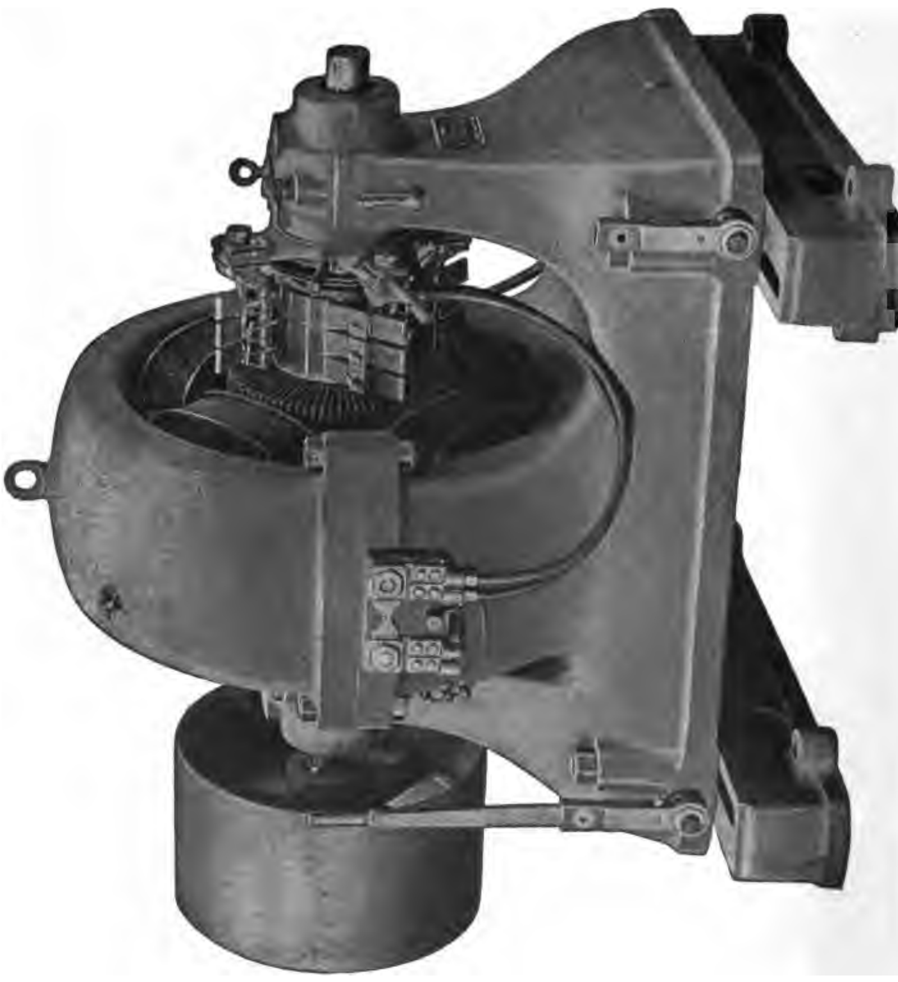


FIG. 530.—FOUR-POLE DYNAMO OF THE WALKER MANUFACTURING CO.

embrace the armature necessitates a very much greater diameter than would be necessary to embrace only the cross section of the pole pieces. The armature of this machine is shown in Fig. 527, and the rocker and brush-

holders in Fig. 528. This form of field-magnet is very suitable for motors when a neat external appearance is a desideratum, as in the case of fan-motors suspended from the ceiling.

If Sayers's compensating winding, described on page 395*, is employed with such machines, the dimensions of the field-magnet may be still further reduced, because by giving a backward lead to the brushes (as is

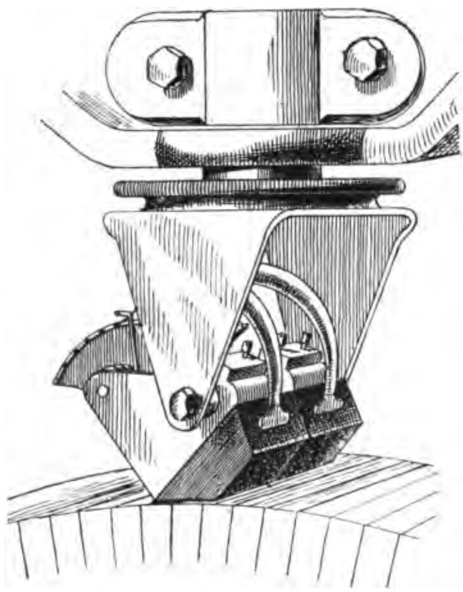


FIG. 531.—WALKER BRUSH-HOLDER.

possible with such windings) the current in the armature is made to assist in exciting the field instead of opposing the excitation. Indeed, a dynamo (to be used as a series dynamo or as a series motor) might be made without any winding on the field-magnet at all. Fig. 529 shows a recent form of Sayers's dynamo made by Mavor & Coulson, of Glasgow, in which the small size of the field-magnet in comparison with the size of the armature is very conspicuous.

* *Dynamo-Electric Machinery.*—Thompson.

When compensating windings are used to correct the cross-magnetizing and demagnetizing effects of the armature reaction, the brush-holders may be fixed once for all, and need no movable rocker, thus simplifying construction.

In the case of multipolar machines there is very much less variation shown in the general shape of the field-magnets. The types shown in Figs. 530 and 533, in which the lower portion or yoke of the magnets, the

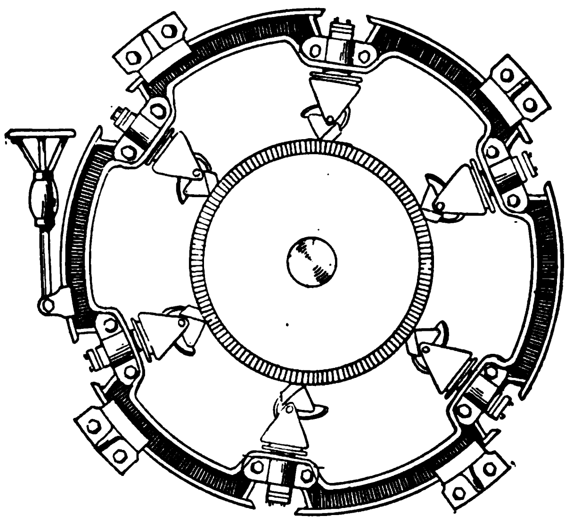


FIG. 532.—RING-SUPPORT FOR WALKER BRUSH-HOLDER.

bed-plate, and the bearing standards are cast in one piece are becoming almost universal. The four-pole generator of the Walker Manufacturing Company, shown in Fig. 530, may be cited as an instance of this type of machine, possessing modern details of construction. The Walker Company has recently brought out a new brush-holder*, a sketch of which is shown in Fig. 531. A ring-support for a whole set of brushes is shown in Fig. 532. The dynamo can rotate in either direction,

* *Electrical World*, xxvii., p. 649, or *Engineering*, March 20th, 1896.

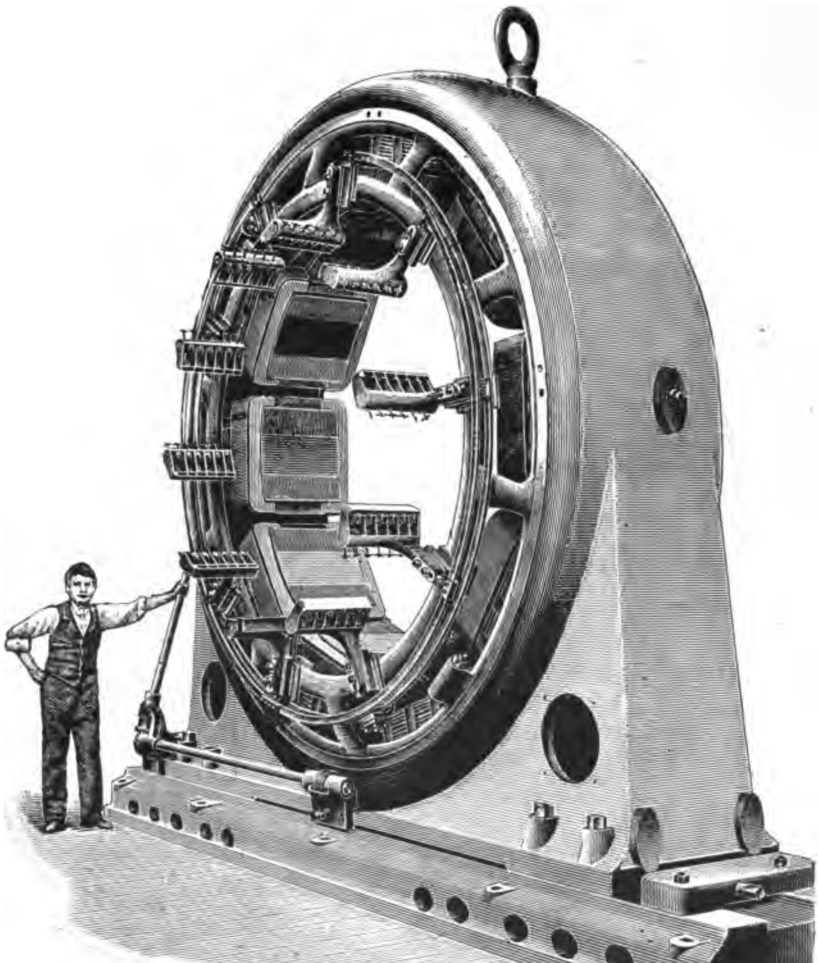


FIG. 533.—RAILWAY GENERATOR (800 KILOWATTS) OF THE WESTINGHOUSE MANUFACTURING CO. OF PITTSBURG.

and is always revolved against the brushes. A spring in the rear gives any desired pressure to the brush by a single adjusting motion. As the holder is always tightly

clamped to its stud with set-screws, contact therewith is secure and sufficient, and the current may be taken directly from the support without special cables.

The use of a ring-support sliding in guides screwed to the field-magnet, instead of a rocker clamped on a rim on the bearing, is now usual with large multipolar machines.

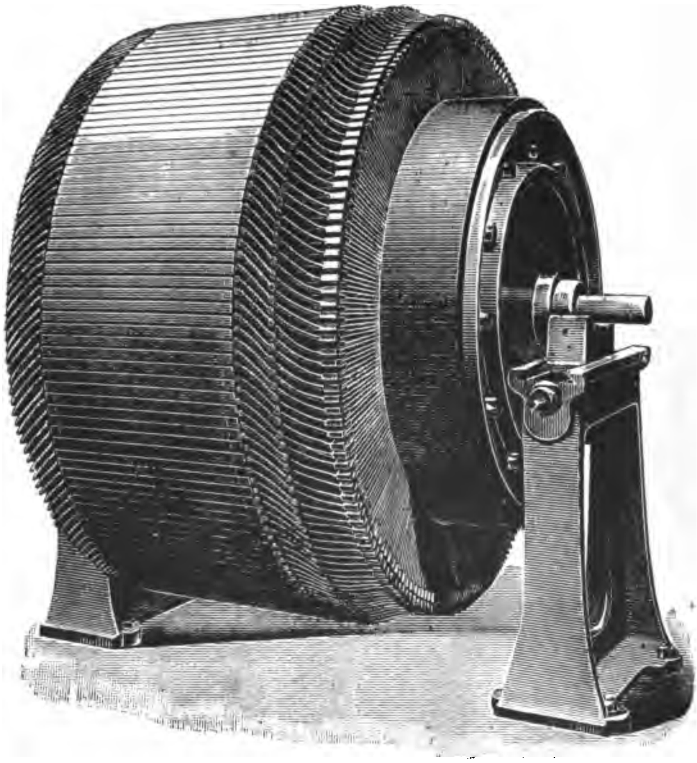


FIG. 534.—ARMATURE OF RAILWAY GENERATOR.

A good instance of a brush-holder of this type is afforded in Fig. 533, which illustrates the field-magnet and frame of an 800-kilowatt electric railway generator made by the Westinghouse Manufacturing Company, of Pittsburg, Pa. When the field of the machine has been bored, a cutter attached to the bearing-bar forms the

groove in which the brush-holder rests, thus insuring perfect centring for the brush-holder, and enabling it to have greater stability. Being in a circular form with the various brushes attached to it, one man, as shown in the engraving, by means of the worm-gear can adjust all the brushes at once, and should anything go wrong with the armature and any serious sparking arise, he can adjust the brushes while being out of harm's way.

Carbon brushes thickly plated with copper are used, and the brush-holders are so arranged that any one brush can be examined and taken out from the machine while it is running, without in any way affecting the working of the generators.

The armature of this machine is shown in Fig. 534.

Fig. 535 shows a Crocker-Wheeler multipolar dynamo of 100 kilowatts capacity for direct attachment to a high-speed engine. The dynamo has a number of special features, including a small hand-lever at the top, by which the eight sets of brushes are raised and lowered upon the commutator simultaneously through the medium of connecting-links. The brushes are attached directly to, and are supported by, two large rings which receive the current.

These rings are fastened together with insulating spacing blocks between them, and rotate as a unit under the action of a screw hand-wheel at the side of the machine, upon the faced edges of four arms which project from the frame of the machine. The entire arrangement leaves the brushes and commutator and the points of contact very accessible and free for observation. The supporting hub of the armature is split two thirds of its length, and is made to pinch the shaft by heavy transverse bolts, the arrangement being such as to secure a very true armature, and one which can be removed and put back very easily.

The principal improvements that have been introduced in this machine are the method of supporting the brushes and the device for raising the brushes from the commuta-

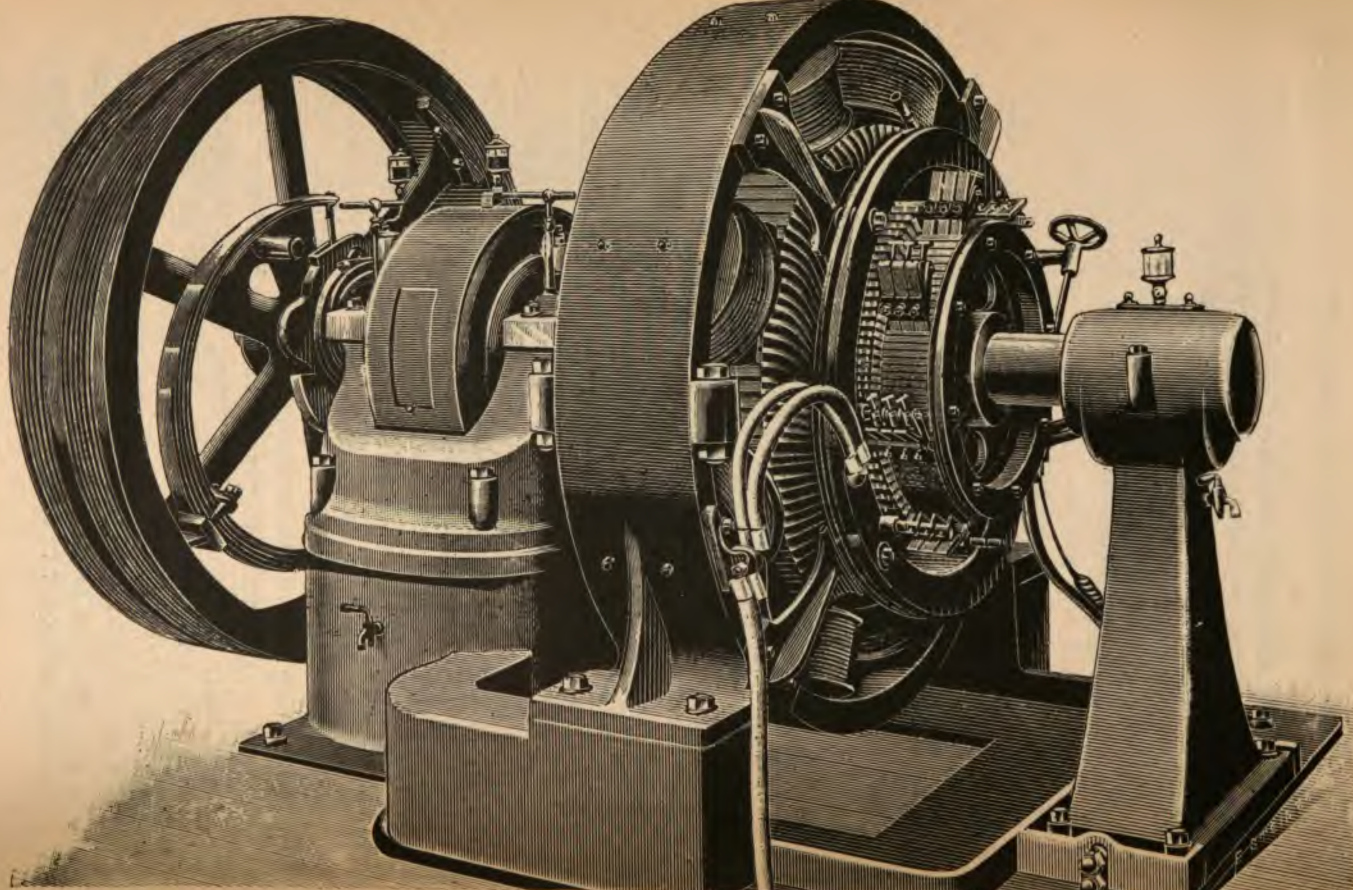


FIG. 535.—CROCKER & WHEELER MULTIPOLAR DYNAMO OF 100 KILOWATTS.

tor. The brush supports, which consist of two rings of iron, act at the same time as connectors between the brushes of the same polarity. They are, of course, insulated from each other, and are insulated themselves with rubber tape and shellac. This device does away with the usual external method of brush support, and leaves the commutator free for inspection, allows ready access to the brushes, and enables the tender to watch the operation of his machine. This particular machine has eight sets of brushes connected four and four. The eight sets of brushes are all joined together with insulated couplings and by a system of levers so arranged that they can all be lifted at one operation. This is to prevent any damage occurring to the brushes by reason of the reversal of the engine when starting. The armature has a ring core with a drum winding. The slots in the armature are of the overhanging type, the conductors being passed through insulated tubes of mica and micanite.

CHAPTER II.

ARC-LIGHTING DYNAMOS.

A NUMBER of firms now make arc-lighting dynamos of the closed-coil type discussed on page 465*, and the tendency is to use toothed armature cores.

A general view of an arc-lighter, made by the Western Electric Company, of Chicago, is shown in Fig. 536. The accompanying cuts are given by kind permission of the *Electrical World*. The commutator, which is shown in section in Fig. 537, and externally in Fig. 538, is built up upon a very substantial disk of hardwood veneering mounted securely on a brass flange. This disk is then faced with mica for better insulation—a very important point in these high-voltage machines—and each segment is screwed to it independently of the others. The segments are tapered gently toward the inside, thus allowing slate wedges to be driven in between them, thereby protecting the mica facing from the burning or over-heating effect that might be caused by the flashing of the dynamos. The outside ends of the segments are held rigidly by a compound ring of mica and veneering, and each segment is held in position on this ring by a screw and two dowel pins. The segments are insulated from each other by air spaces, allowing both sides of each segment to be inspected freely and cleaned readily.

With an air-insulated commutator it is found that the burning effect of flashing and short circuits is confined almost entirely to the brushes ; so that even after bad flashing it is not necessary to turn down the commutator, as is the case with those that are built up solid with mica insulation. The carbon brushes feed down and compensate

* *Dynamo-Electric Machinery.*—Thompson.

for the burning as soon as it is over. All parts of the commutator which are connected with the circuit of the machine are on the face of the wooden disk, so that there

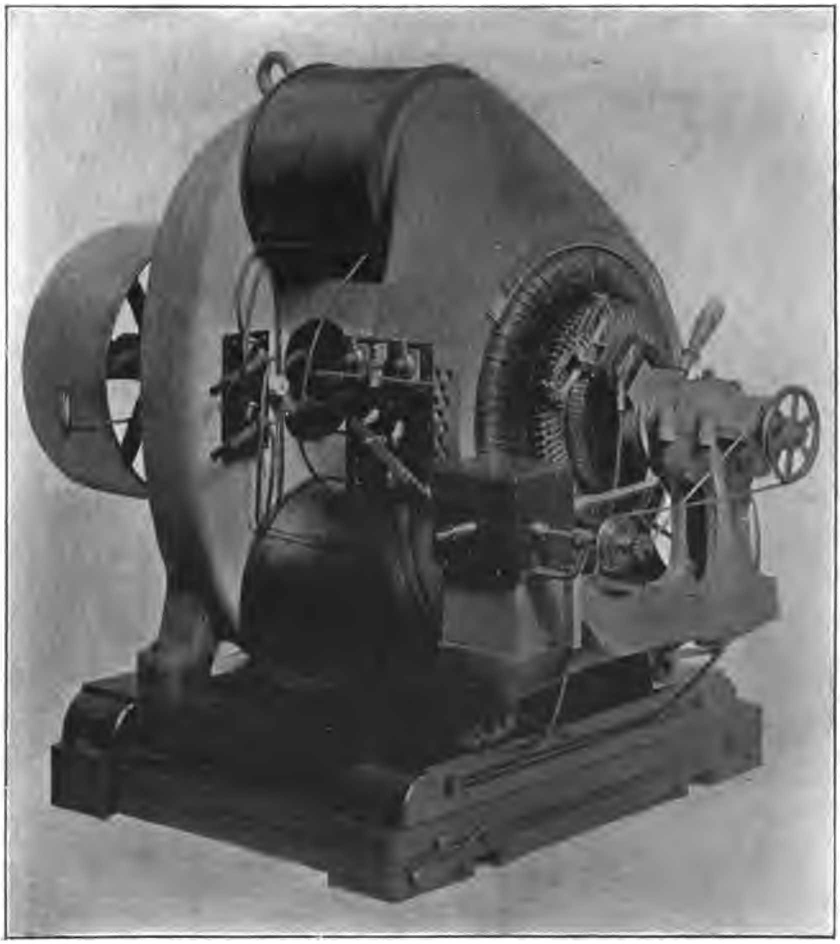


FIG. 536.—ARC-LIGHTING DYNAMO OF THE WESTERN ELECTRIC CO.

are no parts behind the commutator needing to be cleaned to prevent the surface insulation from deteriorating. All screws used in its construction are also accessible from

the front. The segments are increased in size at the working part, so as to provide for long life and also to hold the flashing as much as possible in the working part of the segments.

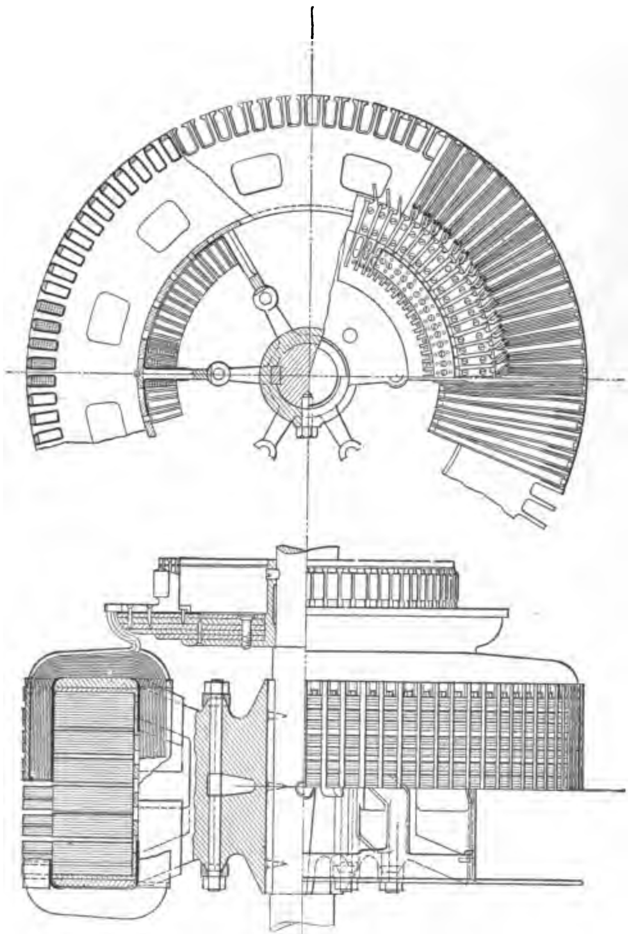


FIG. 537.—COMMUTATOR, IN SECTIONS, OF WESTERN ELECTRIC CO.'S ARC-LIGHTING DYNAMO.

The brushes are arranged to cover the commutator over the entire angle spanned by them ; whatever sparking occurs is concentrated at the tip of the brush. At the brush-tip there is provided a small independent

brush, which is automatically fed downward to compensate for the increased wear due to sparking at this point. This independent brush is so narrow that the brush-

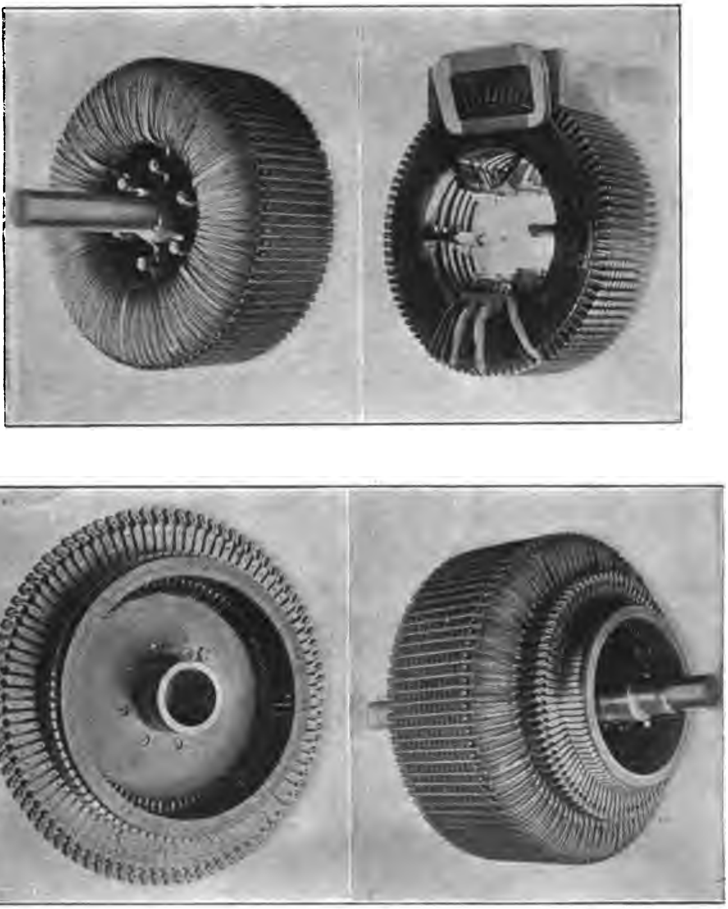


FIG. 538.—FOUR EXTERNAL VIEWS OF COMMUTATOR OF WESTERN ELECTRIC CO.'S ARC-LIGHTING DYNAMO.

angle remains practically constant, no matter how fast the brush may be worn away by the sparking.

The sheet-iron rings of which the armature core is

built up have teeth similar to those of toothed armatures for incandescent lighting. The coils are wound in the slots between the teeth, and are firmly held in place by wooden wedges, which are driven in over the top of the winding. There is a very large number of individual coils, each of comparatively few turns of wire, so that the voltage in any one coil is reduced to such an amount as to obviate flashing under ordinary working conditions.

In case one or even four or five coils of the armature become injured, it is not necessary to rewind them at once, for if a coil is not short-circuited internally, its ends can simply be disconnected from the clamp on the commutator and a small copper wire bridge or "jumper" be put across the segments to which it was previously connected ; and the machine can be run without serious increase in sparking until such time as it is convenient to make a complete repair of the injured coil. In a test made for the purpose of trying this remedy, as many as sixteen coils were cut out without incapacitating the machine. The armature yields a little over 10 amperes at 4300 volts, and is an example of a wonderfully hardy high-voltage armature of the closed-coil type.

CHAPTER III.

ALTERNATE-CURRENT MACHINERY.

THE most recent advances in alternate-current machinery have been made in connection with polyphase plant, most of the manufacturers having settled down some years ago to standard forms in the case of single-phase alternators. There are, however, two or three notable types of alternator which have come into existence during the last year or so. One of these is the 1000-kilowatt 10,000-volt alternator designed and built by Mr. S. Z. de Ferranti for the Deptford Station. This machine is shown in Fig. 539. Among its principal features is the construction of the wheel upon which the armature is built. On account of the high circumferential speed (9800 feet per minute) at which it runs, special precautions have been adopted to make it perfectly safe. The following description is taken from the *Electrical Engineer* :

" Following the construction in order of building up, the first operation consisted of shrinking on to the turned shaft a steel boss having eight large radial holes drilled and tapped in it. The wheel itself is cast in two halves, each half having four double T-arms which rest on the boss. The inner end of these arms was not joined together in casting, so that each was free to move as contraction took place. These two halves of the wheel were faced at the joints, and are turned both in the rim and at the centre. The wheel is then secured in position by shrinking over the end of the arms two heavy steel rings. The ring on the one side can be easily seen in Fig. 539. The two halves are also bound together at the rim by shrinking oval-shaped straps of rectangular section over

projections on the inner side of the rim. These straps are of steel, and have the same section as the rings securing the arms to the boss. The next step is the introduc-

FIG. 539.—FERRANTI ALTERNATOR, 10,000 VOLTS, 100 AMPERES.

tion of eight strong radial spokes of cast steel to help take the bursting stress. These have flanged heads let into the rim and screwed into the boss referred to above. The method of securing uniform stress in each of these

is as follows : The eight spokes are screwed up as far as possible when cold, and then are carefully marked. A calculation is 'then made as to how much further they must be turned to give a definite strain in them. This position is marked, and the spokes are heated *in situ* till the expansion allows of their being readily turned in the position required. On cooling, therefore, each spoke exerts a uniform binding pressure on the rim. The design was based on the assumption that the wheel should carry twice the weight at twice the speed, and the careful workmanship has resulted in a wheel which runs perfectly true.

" The armature of the alternator is built up on somewhat similar lines as in the older Ferranti machines running at Deptford (see page 616*), but with improved details. The internal segments have cores made of laminated brass and asbestos, keyed together by corrugations in the brass. The smaller end is of solid brass burnt on to the strips, and to this is connected the inner end of the bare copper conductor. The segment is then wound with the conductor, which has corrugations to prevent side displacement, and the adjacent turns are insulated by special fibrous material. Two adjacent segments are clamped together into one carrier, and the outside ends of these conductors are connected where they touch. The two bolts clamping them into the carrier then form the two connections to the segments. The insulation between the carrier and the coils is effected by micanite shields. The carriers consist of two heavy brass castings clamped on to the segments. The complete carrier is supported on two bolts projecting from the rim. The insulation of these bolts is a matter of the greatest importance. They are ebonized all over except at the thread. The heads, screwed on, which come in the rim are covered with ⅜-inch of ebonite. The rim of the flywheel is cast with a series of chambers to contain these bolt-heads. When they have been inserted and are held

* *Dynamo-Electric Machinery.*—Thompson.

exactly in position by a template, the surrounding space is cast in with a special insulating compound of sulphur. These bolts are then tested with 20,000 volts between the metal at the screwed end and the rim of the wheel. The whole armature is connected up into two parallel circuits in such a way as to prevent any large difference of potential between adjacent segments. The connections are made from diametrically opposite points on the armature. The one point is earthed by being connected on to the rim of the wheel, and the opposite point, which is at 10,000 volts above the earth, is led by highly insulated connection to a collector in the front of the machine. The bolts supporting the carriers near the high-tension connection have extra insulation on them, consisting of a series of ebonite collars, which increase the length of surface liable to leakage. The field-magnet castings are built up in two halves, one supporting the magnets on each side of the armature. Each half is formed of four segments securely bolted together. The poles, of which there are 64 on each side, are of circular section, and are forced into holes in these castings by hydraulic pressure. The diameter of the poles is so arranged that the fit in the casting practically secures them, but they are also clamped by cup-shaped set screws. The field coils are constructed by winding bare copper strip on edge into a spiral, with insulation between adjacent turns. The whole of these coils are connected in series, and at full load the machine requires about 1 per cent of the full power for excitation. The section of the magnets is not increased at the pole-faces. The danger of the high voltage from the bare copper of the armature sparking across to the field has been overcome in this case by placing micanite caps over the poles. These caps, which are about $\frac{1}{8}$ inch thick, have all been tested up to 25,000 volts. Since being in use no faults have developed in them up to the present. The caps are enamelled on the outside, and even then have to be wiped all over after about every 24 hours of running to prevent surface

leakage. To enable this to be readily done, the two halves of the field-magnet system are made to slide, and are moved apart by a screw gear driven by an electric motor. This electric gearing is placed on the edge of the armature pit next to the engine, and by means of it the magnets can be separated in five minutes. In fact, on a special occasion it was found that three quarters of an hour was all the time taken to separate the fields, to remove a defective segment, to replace it by a new one, and to bring the magnets back into the position for running.

"Some idea of the size of the machine can be gained from the illustration, but the following few dimensions will be of interest in this respect: the outside diameter of fly-wheel is 16 feet; mean diameter of armature—*i.e.*, diameter of pole centres—20 feet; over all diameter, 24 feet; width of armature strip, $\frac{3}{4}$ inch; circumferential speed of armature at mean diameter, 9800 feet per minute. The copper loss in the armature at full load is .85 per cent.

"This alternator has been running for over a year now, and has been tested with 75 per cent of the full load on it. A neat method of indicating the relative speed of the machine before putting it into parallel with the others is in use. A series of white patches are painted on the rim of the fly-wheel, opposite alternator coils. An arc lamp is then supplied from the other source of alternating currents. As is well known, the light given off by an alternating arc is not continuous, but fluctuates with the alternations. Hence, when looking at an object lighted in this way, a series of consecutive impressions is received on the retina. So, when observing the white patches referred to, one really sees their positions at successive definite points on the current curve of the other alternator. If the two machines are absolutely in synchronism, the result is that the spots appear stationary. If there is a difference of speed, they seem to advance or recede according as to which machine goes faster. In this way

the driver gets a good indication as to whether his engine is at the right speed before the usual synchronizer is switched in."

The General Electric Company, of Schenectady, has developed the so-called "monocyclic" system of alternate-current work devised by Mr. Steinmetz. The monocyclic system was designed to replace the old type single-phase system of alternate-current distribution by

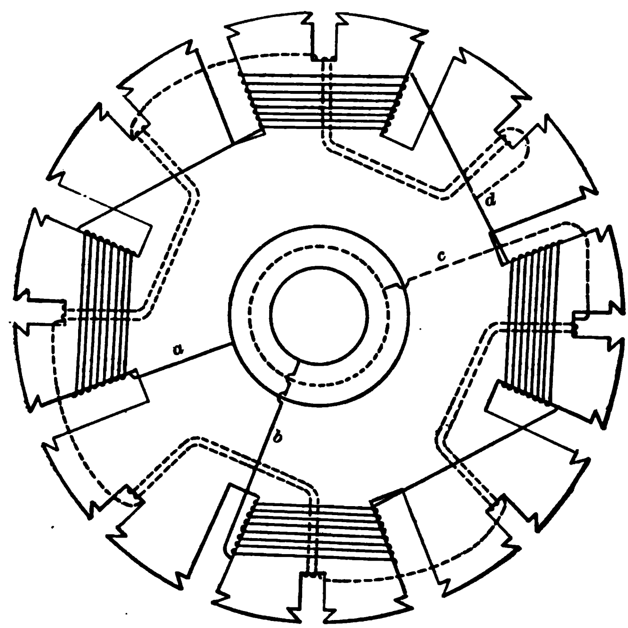


FIG. 540.—MONOCYCLIC ARMATURE.

affording the advantage of being able to supply power to alternate-current motors that shall be self-starting under full load without affecting the steady working of the lighting system. By the courtesy of the *Electrical World* we are able to give here a short description of this system, and some figures of the plant. The monocyclic generators differ from the old single-phasers only by having midway between the main slots that receive the windings

on the armature a second set of small and shallow slots, as shown in Fig. 540, which contain a supplementary or "teazer" winding shown in dotted lines.

The "teazer" coils have only one quarter of the number of turns of the main coils, and therefore give only one quarter as much electromotive force. The teazer winding is connected with one end to a third or middle collector-ring, and with the other end to the middle of the main winding, as shown diagrammatically in Fig. 541. It will be evident that the current in the teazer winding will be out of phase with the main current. Further, as the current going out from the teazer coil has

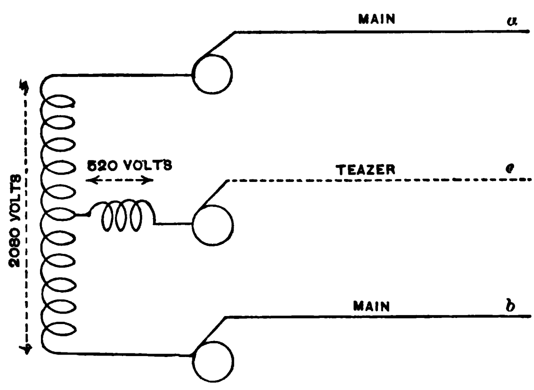


FIG. 541.

to return through one or other half of the main coils, it meets with a considerable self-induction. This feature, causing a relatively higher impedence in the teazer circuit, limits the flow of current in that circuit by causing the voltage in this part to drop as current is taken through it, so that the power put forth by the alternator is practically all conveyed by the current of the other winding in the same way as in the old single-phase system. In other words, the teazer current is almost entirely a watt-less or idle current, useful for giving a starting torque to motors, which are connected up with a third wire to the teazer line, but not really contributing

anything to the driving power when the motor has got up speed.

The teazer voltage of the generator cannot be measured directly, since only one terminal of the teazer winding is accessible when the armature is rotating. The potential difference between the two main or outside collector-rings is simply that due to the main coil. The difference of potential between the middle or teazer collector-ring and either of the two main collector-rings is the resultant of the teazer voltage and half the main voltage.

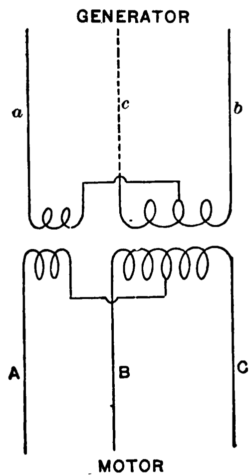


FIG. 542.

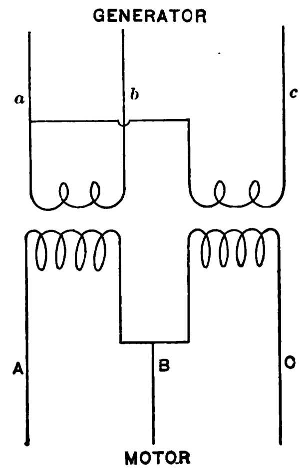


FIG. 543.

Since the teazer voltage at open circuit is one quarter of the main voltage, and the difference of phase between them is 90°, the relative voltage will be

$$= \sqrt{(\tfrac{1}{4})^2 + (\tfrac{1}{2})^2} = \sqrt{\tfrac{1}{16} + \tfrac{1}{4}} = \sqrt{\tfrac{5}{16}} = 0.57\,;$$

or if the whole voltage across the outer mains is 2000 volts, and that of the teazer coil 500 volts, then each half of the main coil will generate 1000 volts, while the measured difference of potential between the teazer line and either main will be about 1140 volts.

For the operation of induction motors the primary vol-

tage is transformed either by two transformers of equal size, as shown diagrammatically in Fig. 543, or by a large main transformer coupled to a small teazer transformer, as shown in Fig. 542.

The diagram of the electromotive forces corresponding to Fig. 541 is shown in Fig. 544, *a b* being the primary main, and *c d* the primary teazer voltage. Thus the dotted lines *a c* and *c b* are the resultant voltages between main and teazer wires, differing from each other by somewhat less than 60°.

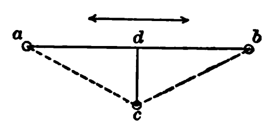


FIG. 544.

Fig. 545 gives a general view of a large monocyclic armature. The proper sizes of the main and teazer wires are very simply determined. The main conductors are calculated as for a regular simple alternate-current system, and then the ratio between the cross-section of the teazer winding and the cross-section of the main winding is made the same as the ratio of the total motor load to the total load (for lamps and motors together) of the machine. It is, therefore, assumed in designing such machines that it is known how much the relative outputs for lamps and for motors will be. Fig. 546 shows the magnet frame of a monocyclic generator in course of construction. The tool for boring out the field is mounted on a temporary axle, and geared up to an electric motor in the manner clearly indicated in the figure, and needing no further description.

An account of the General Electric Company's modern polyphase plant will be found in the *second* edition of the author's treatise on *Polyphase Electric Currents.*

The Westinghouse Company, which holds the Tesla patents in America for polyphase work, has during the last two or three years built and equipped at Pittsburg, U. S. A., a new factory for the special development of alternate-current machinery. Power is transmitted throughout this factory by means of two-phase alternate currents. In choosing one of their many types of alter-

nators to illustrate here we cannot do better than select one of the machines which the company have themselves chosen to do their own work. Fig. 547 depicts one of the 500 H.P. direct-connected two-phase generators which supply power to the tools in their factory. This machine stands a little over 8 feet high. Its appearance

FIG. 545.—MONOCYCLIC ARMATURE.

of compactness and solidity is very striking. It has 14 laminated steel pole pieces built up and cast into the yoke. The exciting coils have a simple winding, regulation being secured through a rotatory transformer which supplies the total field current. The armature is built on a spider keyed and forced on to a 7-inch shaft. The laminated steel portion is designed to provide thor-

ough ventilation. The periphery is notched with 92 slots, into which the copper conducting bars are inserted, and in which they are secured by means of strips of rigid insulating material secured by grooves inside the slots.

FIG. 546.—MAGNET FRAME OF MONOCYCLIC GENERATOR.

This construction obviates the use of binding wires on the surface of the armature. The winding is a closed one with four connections brought out at such parts of the winding as to yield electromotive forces differing by 90° in phase, on the plan devised by Bradley in 1887 (see

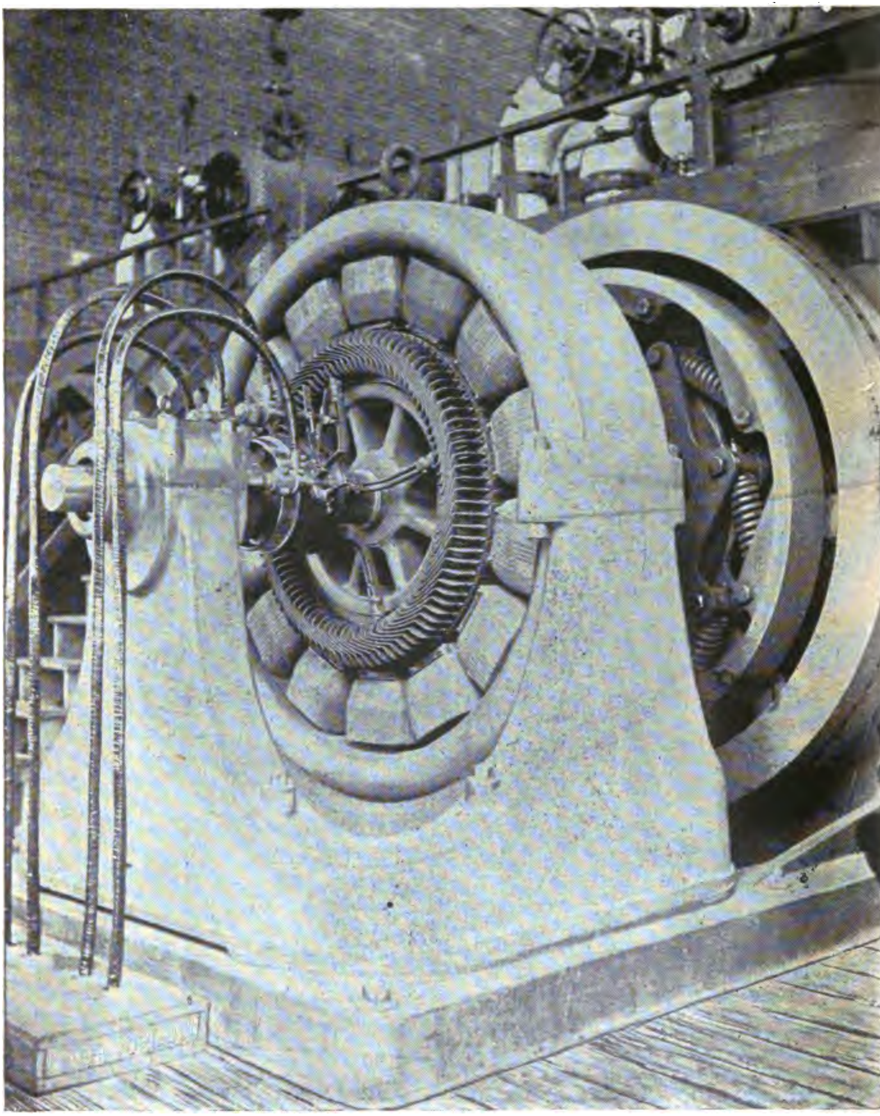


FIG. 547.—WESTINGHOUSE 500 H P. TWO PHASE GENERATOR.

page 599*). The collecting-rings are 5½ inches in diameter with a 1½ inch face. The armature runs at 215 revolutions per minute, giving a frequency of 25 periods per second. The voltage is 240, and at full load the output is 400 amperes in each of the two circuits, the efficiency being 95 per cent. These generators are run in parallel.

Fig. 548 shows one of this Company's 40 H.P. two-

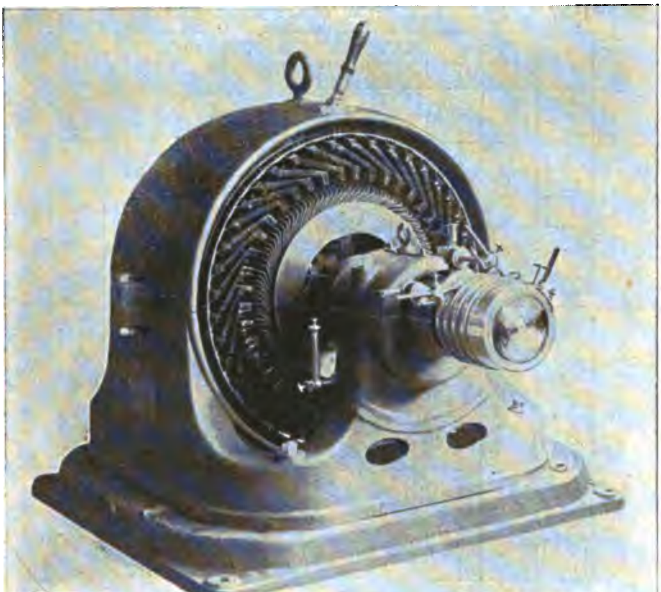


FIG. 548.—WESTINGHOUSE 40 H.P. TWO PHASE STANDARD MOTOR.

phase standard motors. The current is supplied to the moving part, while the secondary winding is stationary. The windings of this secondary (which cannot be called a rotor, since it stands still) are connected together through small resistances which are short-circuited after the motor has got up speed, in accordance with the practice discussed on page 684*. The particulars of the performance of this motor can be studied in the diagram

* *Dynamo-Electric Machinery.*—Thompson.

of curves given in Fig. 549. No curve for starting torque is shown, but it may be made anything desired up to two and a half times the full load running torque by merely inserting a resistance that has been designed to meet the conditions under which the motor is to operate when installed. One and a half times the full load running torque is quite a sufficient starting torque for ordinary conditions.

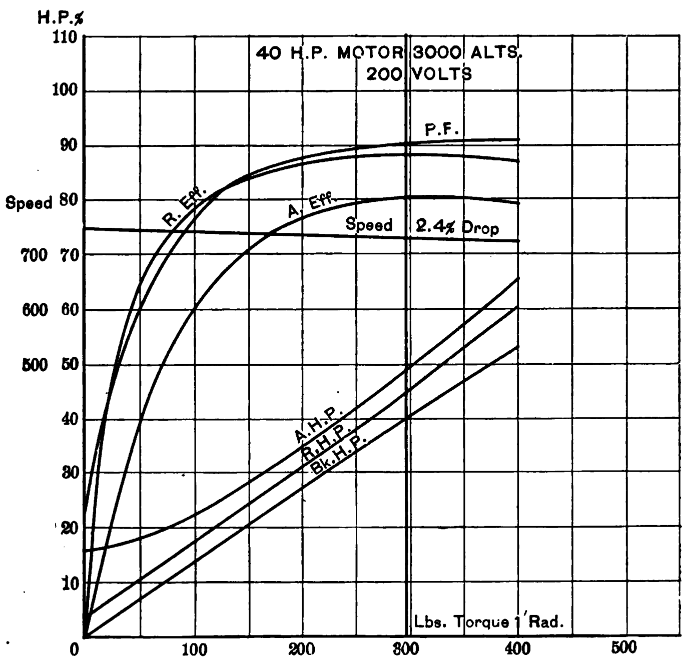


FIG. 549.—CURVES OF 40 H.P. MOTOR.

The Brush Electrical Engineering Company, of London and Loughborough, has introduced a new form of inductor alternator, belonging to the type of machines devised in 1887 by Mr. W. M. Mordey (see his British specifications of Patent Nos. 8262 of 1887 and 5162 of 1888), and depicted in Figs. 439 and 439*a* of the fourth (1892) edition of the present work. The essential feature of this type is the avoidance of any revolving coils, the

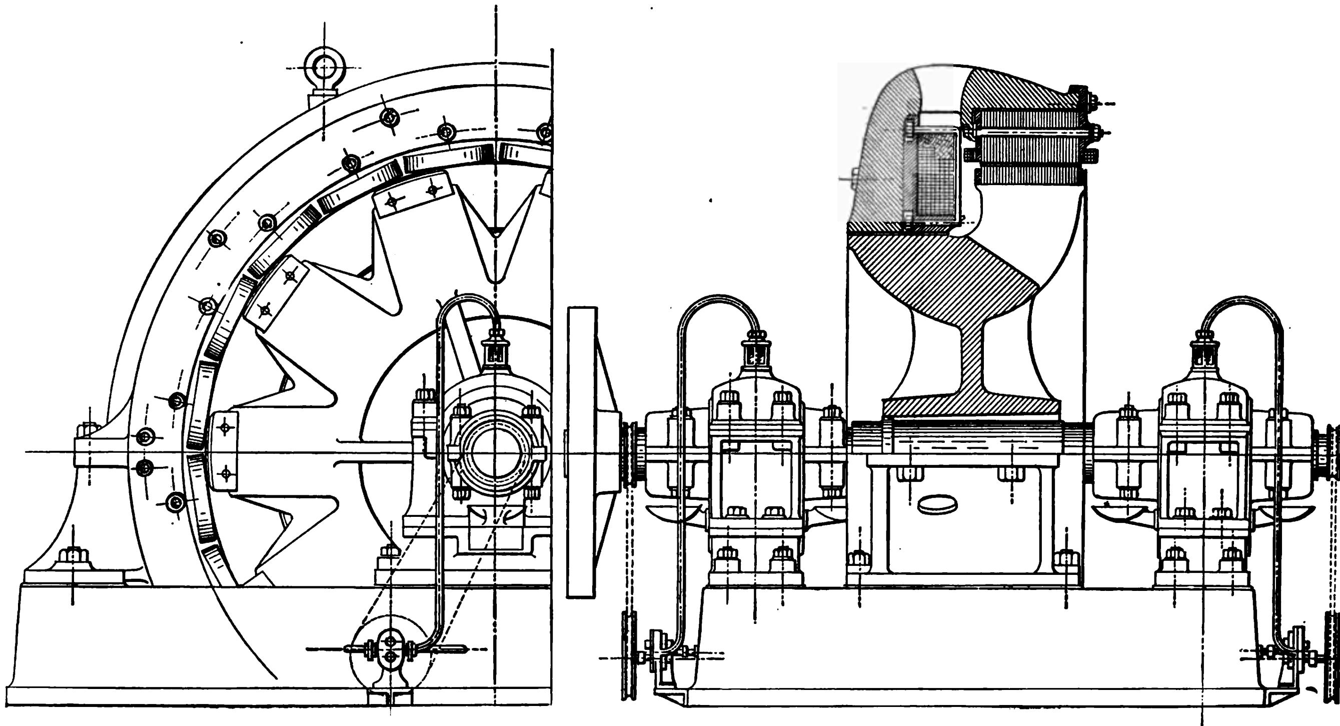


Fig. 550.—New Mordey Inductor Alternator.

rotating part being of iron only, while a single magnetizing coil suffices to magnetize all the individual sets of poles. To this type belong the well-known Stanley-Kelly alternator, and some of the recent forms built by the Allgemeine Company and by the Oerlikon Company. The new Mordey inductor alternator has a certain resemblance to the machine shown in Figs. 436 and 437 of page 643*, but the particular machine of which a sectional view is given in Fig. 550 is simpler. Instead of having a double ring of armature coils, and a double set of laminated polar projections, only a single ring is used in this machine ; and the return path of the magnetic circuit is through a very small air space between the concentric cylindrical surfaces of the inductor port and the armature ring. The armature coils are simply rectangles, built of well-insulated copper wire or strip, placed in slots or grooves in the fixed laminated iron structure, and secured therein by a wooden strip driven into each slot. The slots are lined with a thick channel piece of micanite of U-shaped section, in which the coils repose. As in the older Mordey alternators, the number of armature coils is double that of the revolving pole faces. The single annular field winding so long known in those older alternators is retained, but this winding is now fixed in position on the stationary part of the machine.

* *Dynamo-Electric Machinery.*—Thompson.

CHAPTER IV.

DYNAMO DESIGN.

WITH the progress of dynamo construction there has gone on a simultaneous improvement in the production by metallurgists of special kinds of iron and steel for use in cores of armatures and in magnet frames, and in the methods used by designers for calculating out the designs.

Special brands of very mild cast steel are now manufactured having a permeability actually higher than that of the best Swedish or Lowmoor wrought iron. On the Continent of Europe the eminent firm of Krupp supplies a special soft cast steel known as "Dynamo façon-guss." In England similar steels are manufactured by Messrs. Armstrong, Mitchell & Co., and by several Sheffield firms, including Messrs. R. A. Hadfield & Co. and Messrs. Edgar Allen & Co. Many scientific tests of these and other excellent brands have been made, chiefly by Professor Ewing, who has given a summary of the results in a recent paper read in May, 1896, before the Institution of Civil Engineers. Another important contribution to our knowledge of the subject is afforded by the paper by Mr. Horace F. Parshall read at the same time. To these the reader is referred for the most recent information.

Makers of dynamos who have had experience of designing and constructing dynamos in all sizes and sorts gain experience from practice that serves as a valuable guide in subsequent design. Among the matters which can thus be turned to future use is the degree to which experience shows that it is worth while to push the magnetization in the various parts of a dynamo. If, for ex-

ample, experience has shown that a particular brand of iron can be used in making armature cores, and if experience has also shown that in such armature cores it is best to work with a particular flux-density, then, in assuming this as basis for new designs, one need no longer trêat permeability as a variable quantity, since in a given brand of iron a particular value of the permeability corresponds to each particular value of the flux-density, and this can be ascertained once for all. And if the permeability is known, the number of ampere-turns needed, per inch of length, to produce this particular flux-density in that part is capable of being definitely stated. Then by simply inspecting the drawings, and multiplying the length of each part in the path of the magnetic circuit by the ampere-turns per inch required for that part, one readily reckons up the required winding.

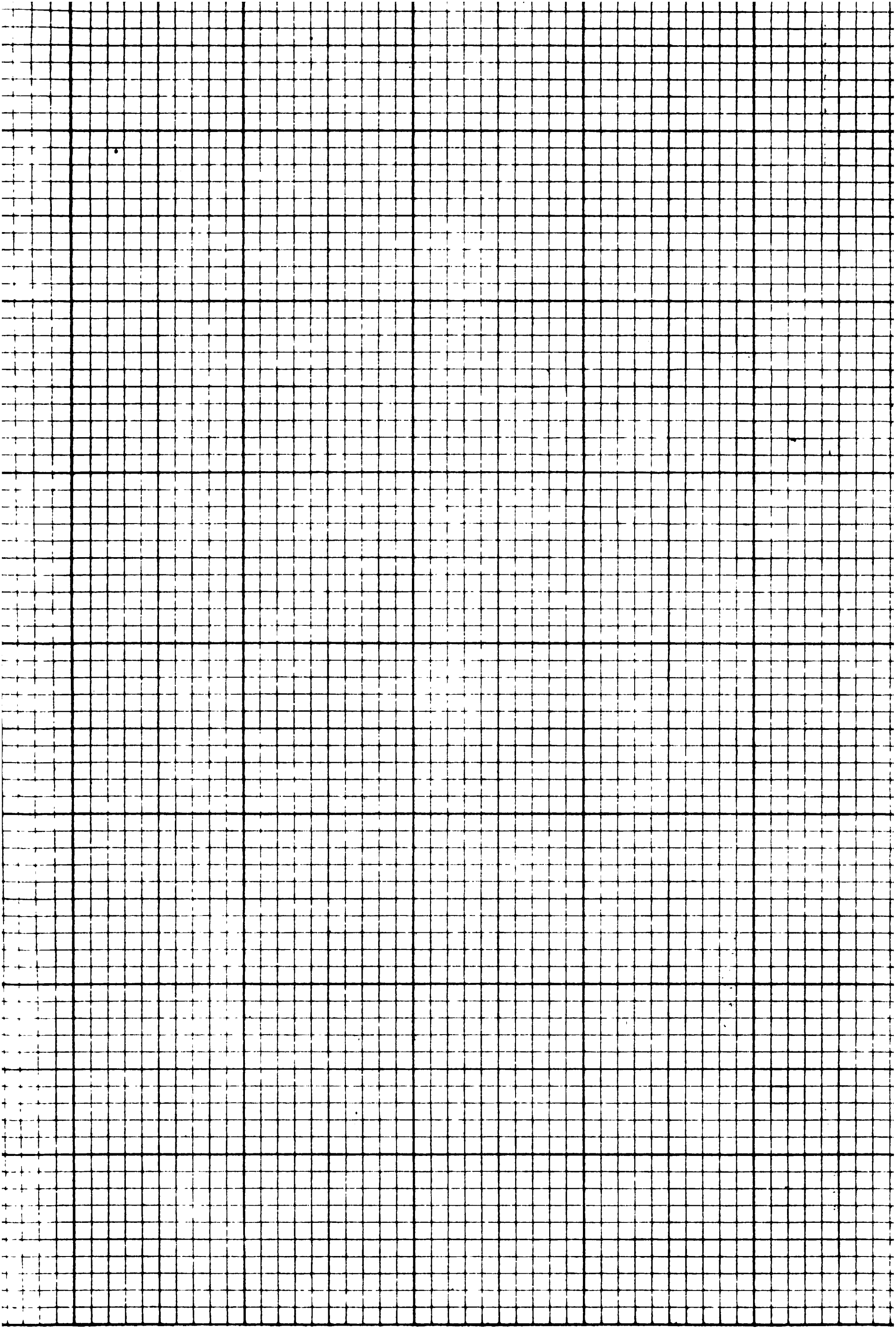
A single example will suffice. It relates to a four-pole 50-kilowatt continuous current machine suitable for use as a railway generator, and generally of the same type of construction as the six-pole dynamo depicted in Plate X., and described on page 434*. The armature was 22 inches in diameter (with 84 teeth), and the length of the core parallel to the shaft was 8·3 inches. It was built of plates of soft iron. The pole pieces and yoke were of a special cast steel. The total flux through any one of the four inwardly projecting poles was 4,546,000 lines, of which about 4,060,000 lines passed through the teeth into the armature core. In the following table, wherein inch-units are used, the several values of ampere-turns per inch-length in the different parts are calculated as follows. From the flux-density (per square inch in this case), which experience has shown to be good, a reference to the magnetic curve (such as Fig. 83, on page 123*) of the particular brand of iron will give the corresponding value of the permeability, and dividing the flux-density by the permeability gives the value of the magnetizing force needed (*i.e.*, $H_{\prime\prime}$), or this may be taken direct

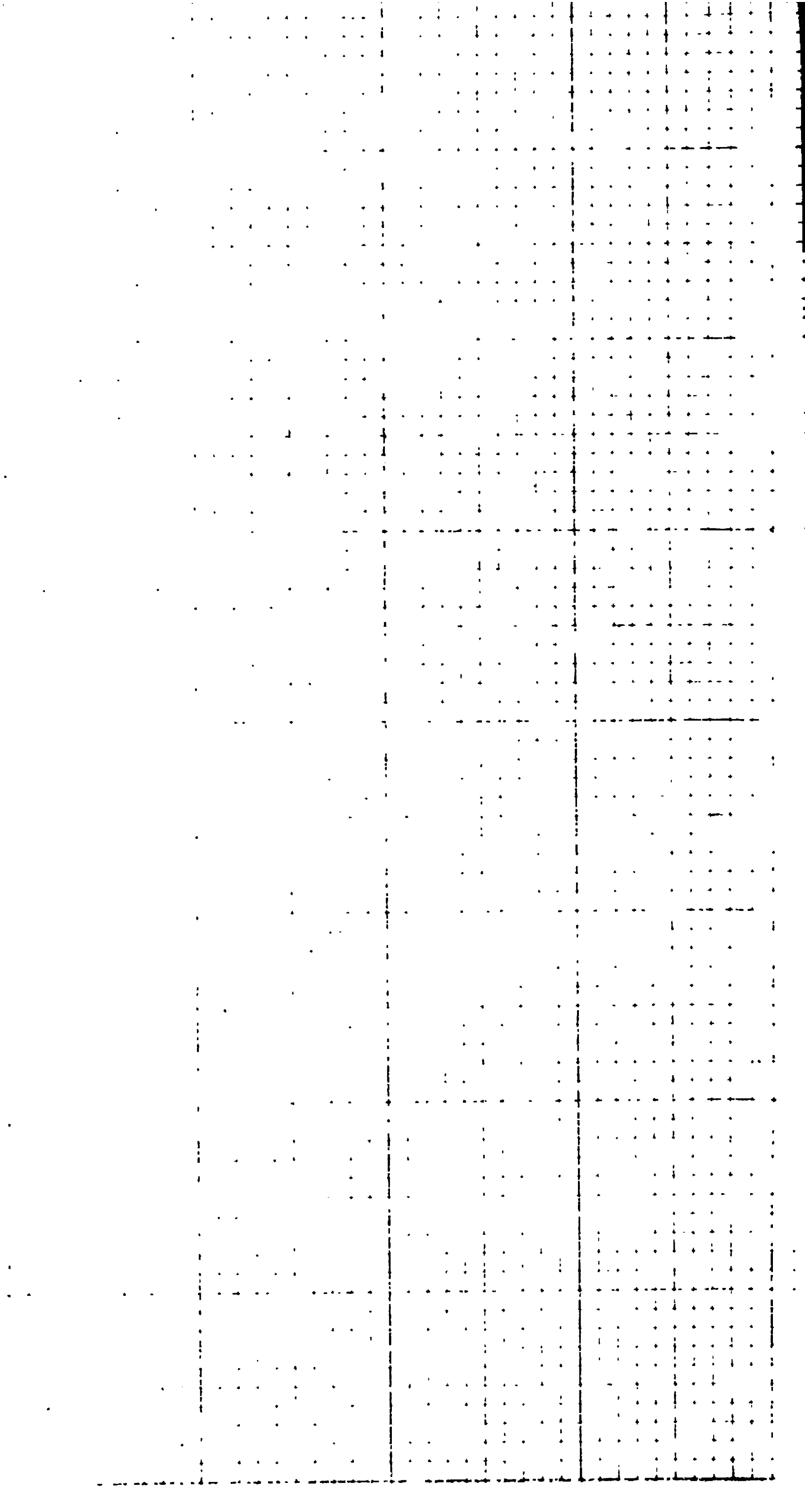
* *Dynamo-Electric Machinery.*—Thompson.

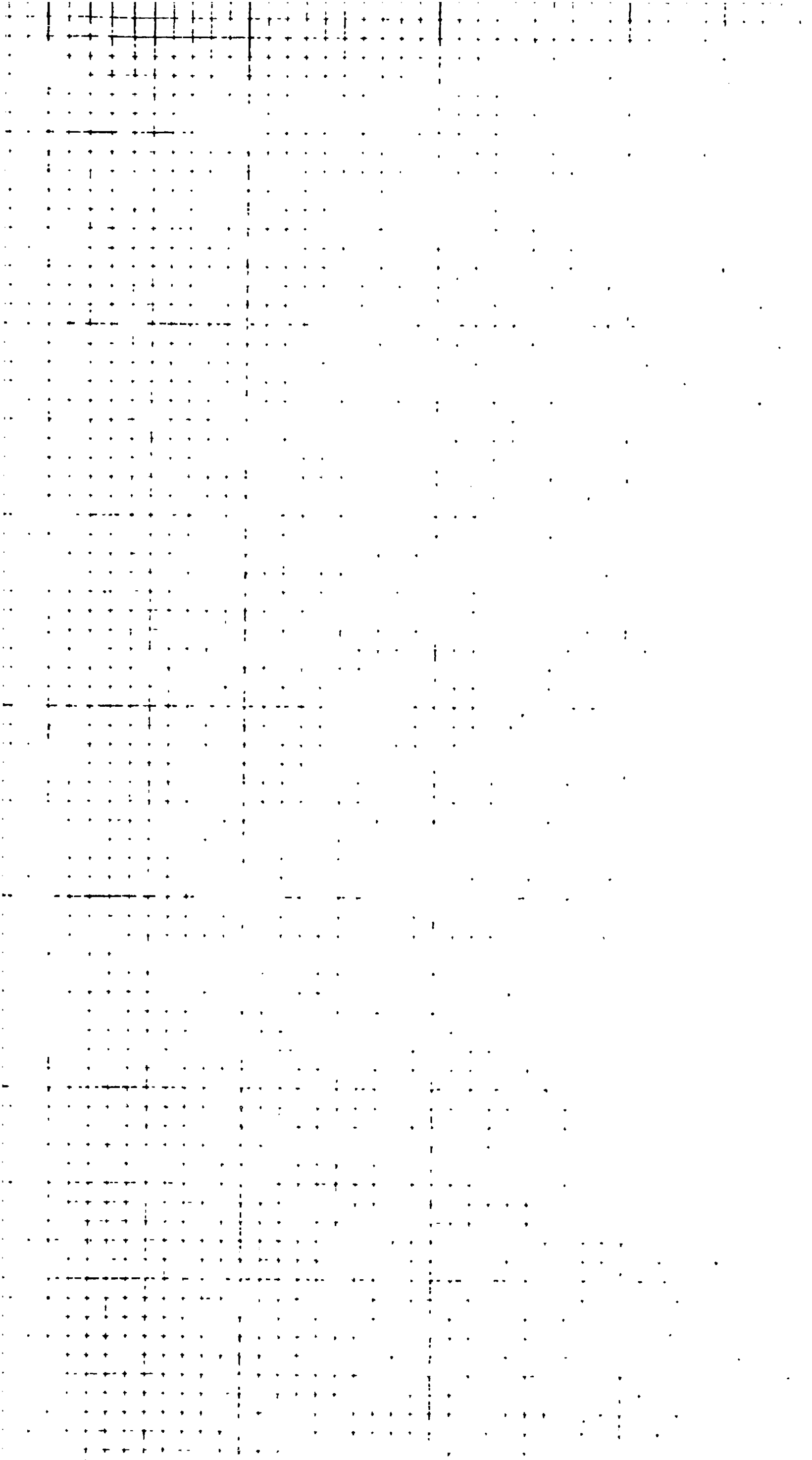
from the curves. By dividing by 6·45 we find the value of H, the magnetizing force per square centimetre, which when multiplied by 10 and divided by 4π gives the number of ampere turns per centimetre of length. Finally, multiplying by 2·54 changes the value to ampere-turns per inch. All this may be done in one operation by dividing $H_{,,}$ by 3·192.

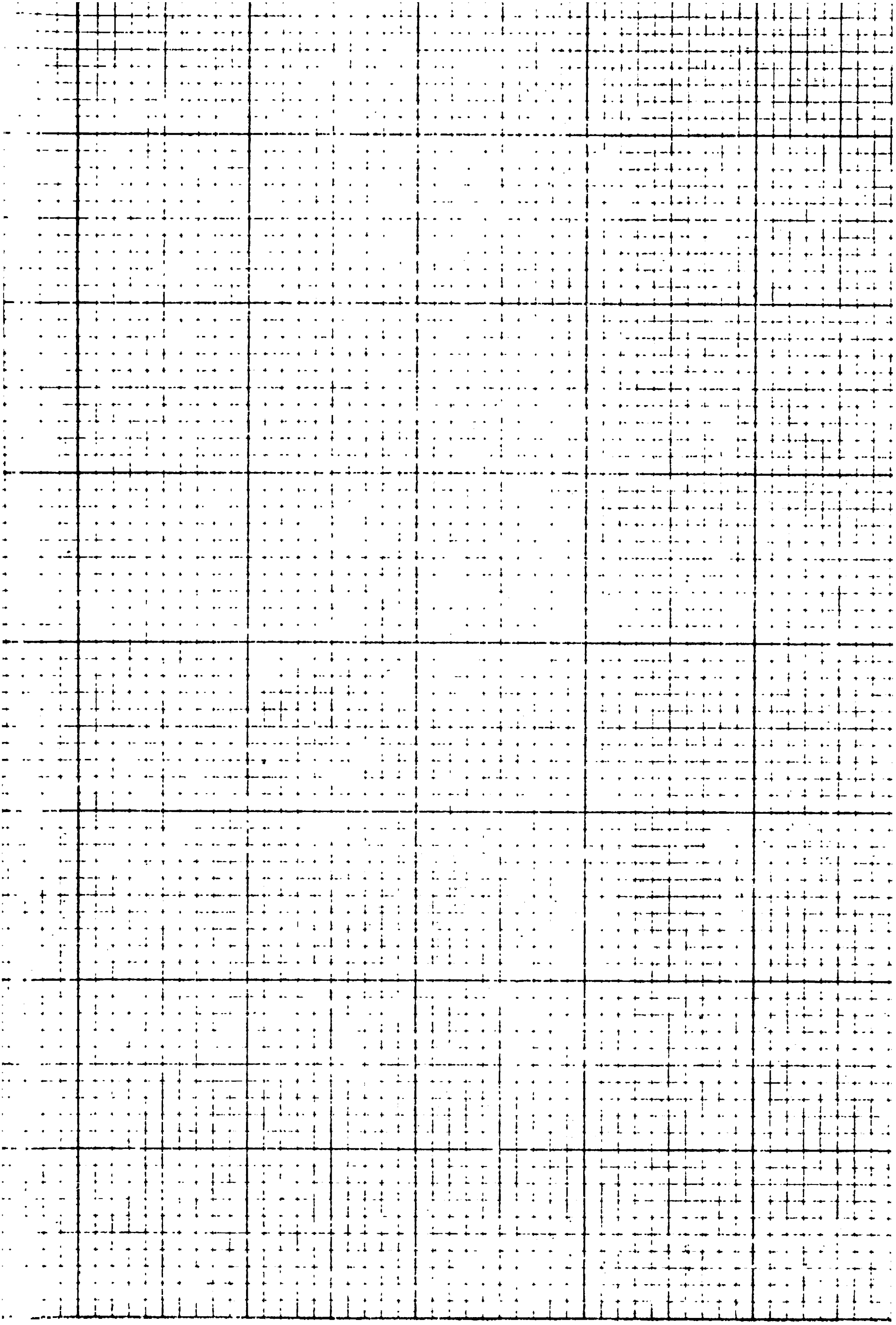
Name of Part.	Magnetic Flux (Mega-lines).	Cross-section (Square Inches).	Flux-Density per Square Inch.	Ampere-Turns per Inch Length.	Length of Part (Inches).	Ampere-Turns Required.
Pole........	4·546	54·11	84,014	36·5	9	328
Yoke......	4·546	37·5	60,450	5·5	17·8	98
Gap	4·06	102·0*	39,800†	12,350	0·1875‡	2,315
Teeth.....	4·06	38·1	106,560	113	1·5	170
Armature .	4·06	33·2	61,140	6·5	7·38	48
Total Ampere-turns on each pole..........						2,959

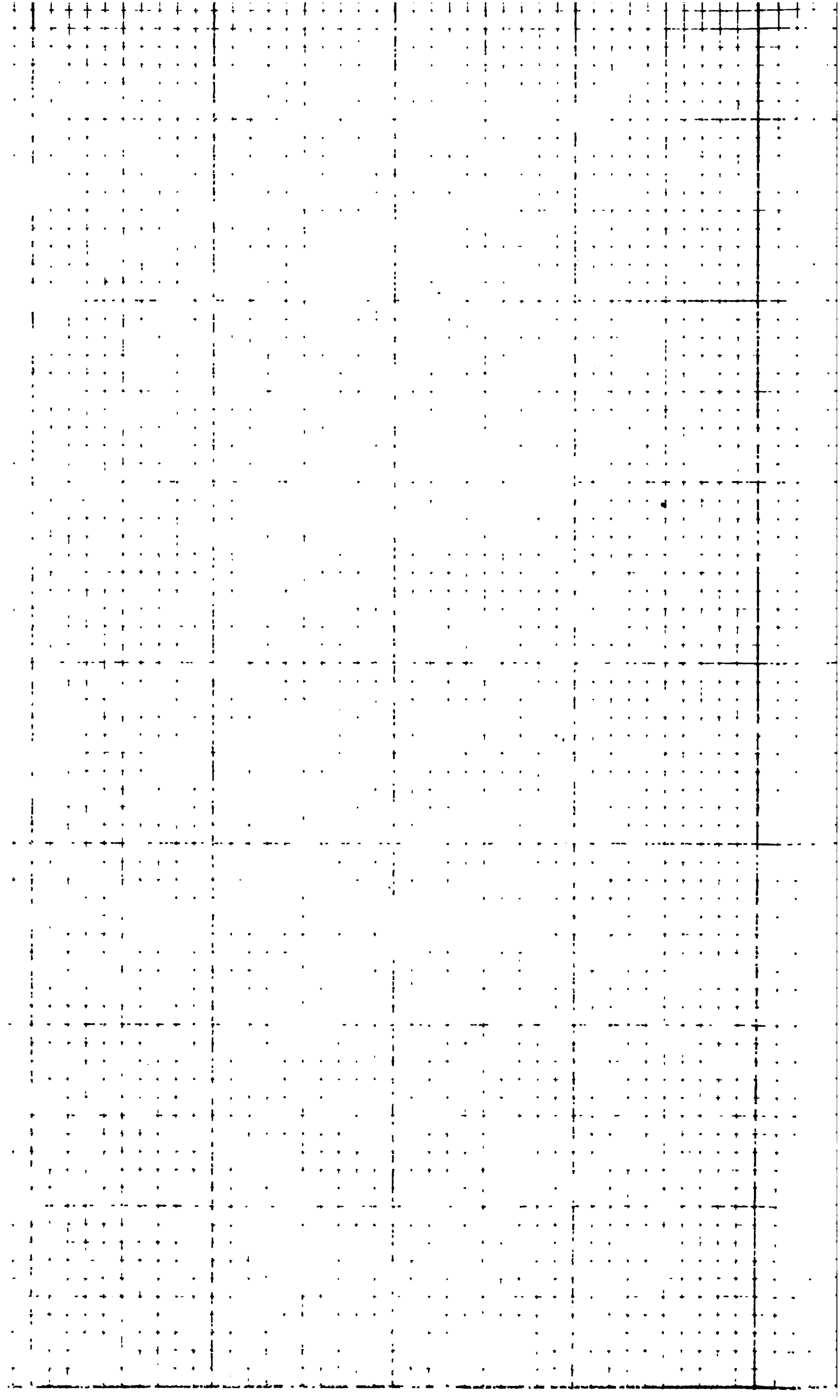
Remarks.—* At pole face; at face of teeth available section is only 52·1 square inches.
† At pole face; at face of teeth flux-density over 75,000.
‡ At one side. As there is winding on each pole, the calculation for each takes into account only one gap, and only one-eighth of total length of circular yoke.

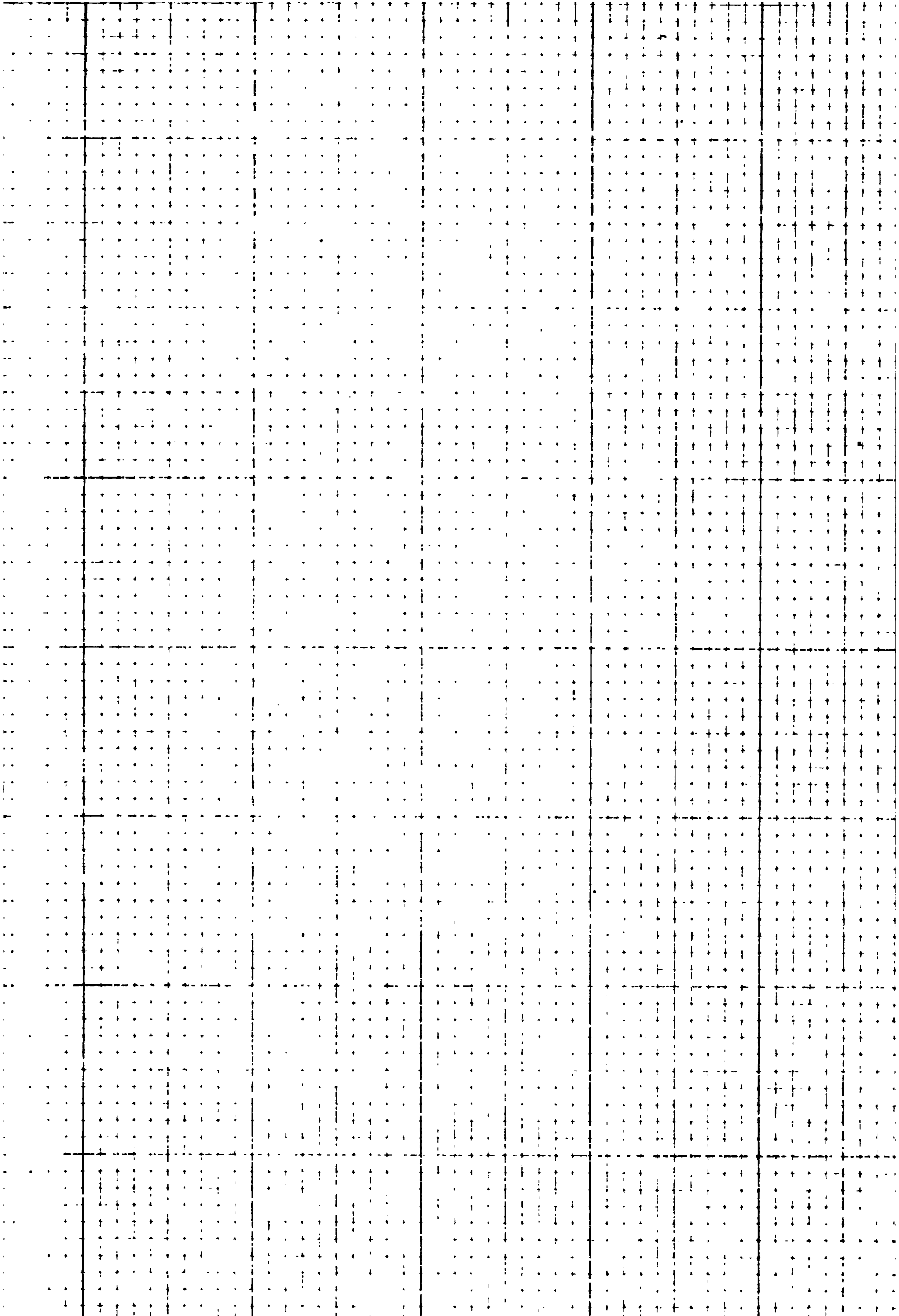


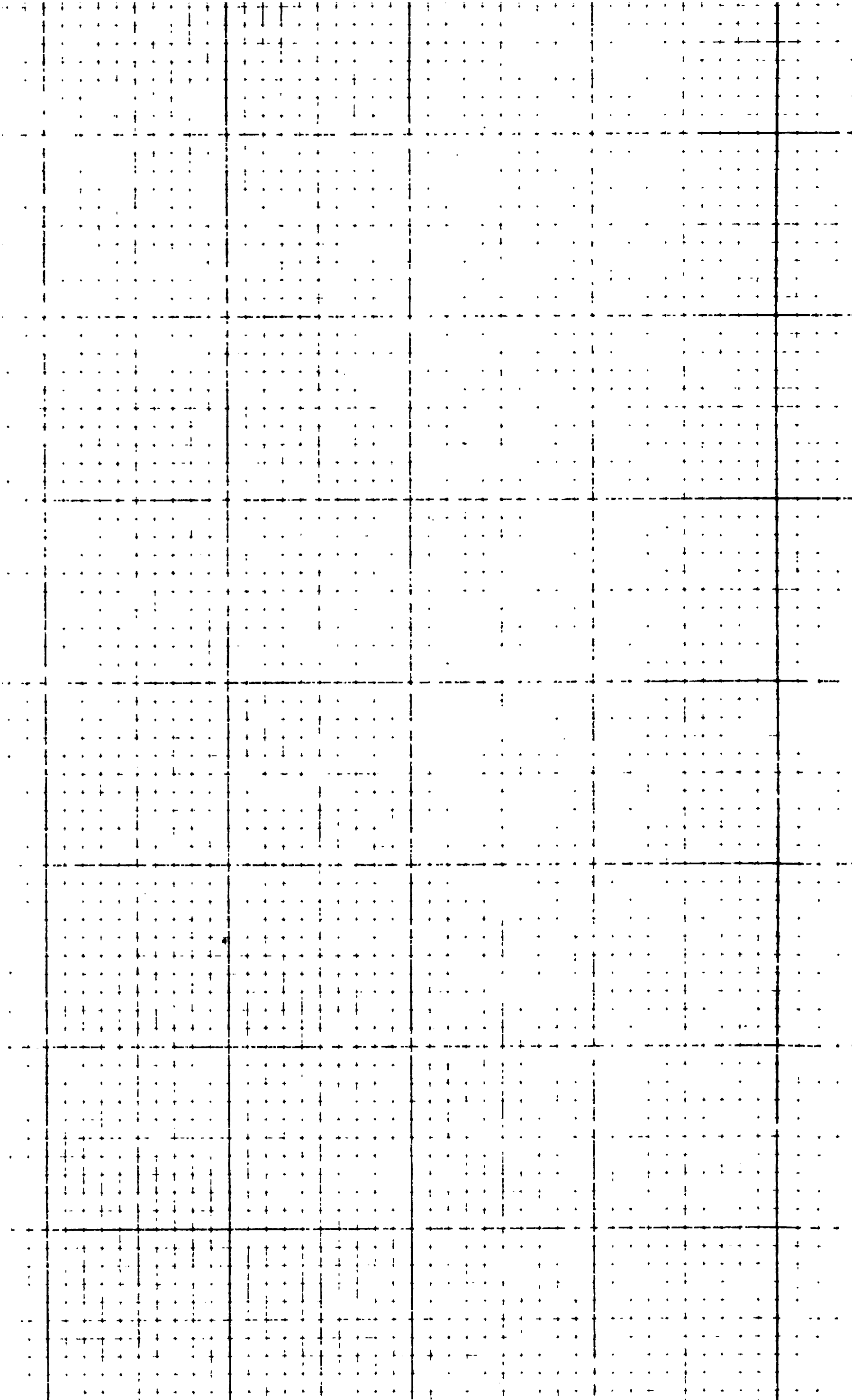












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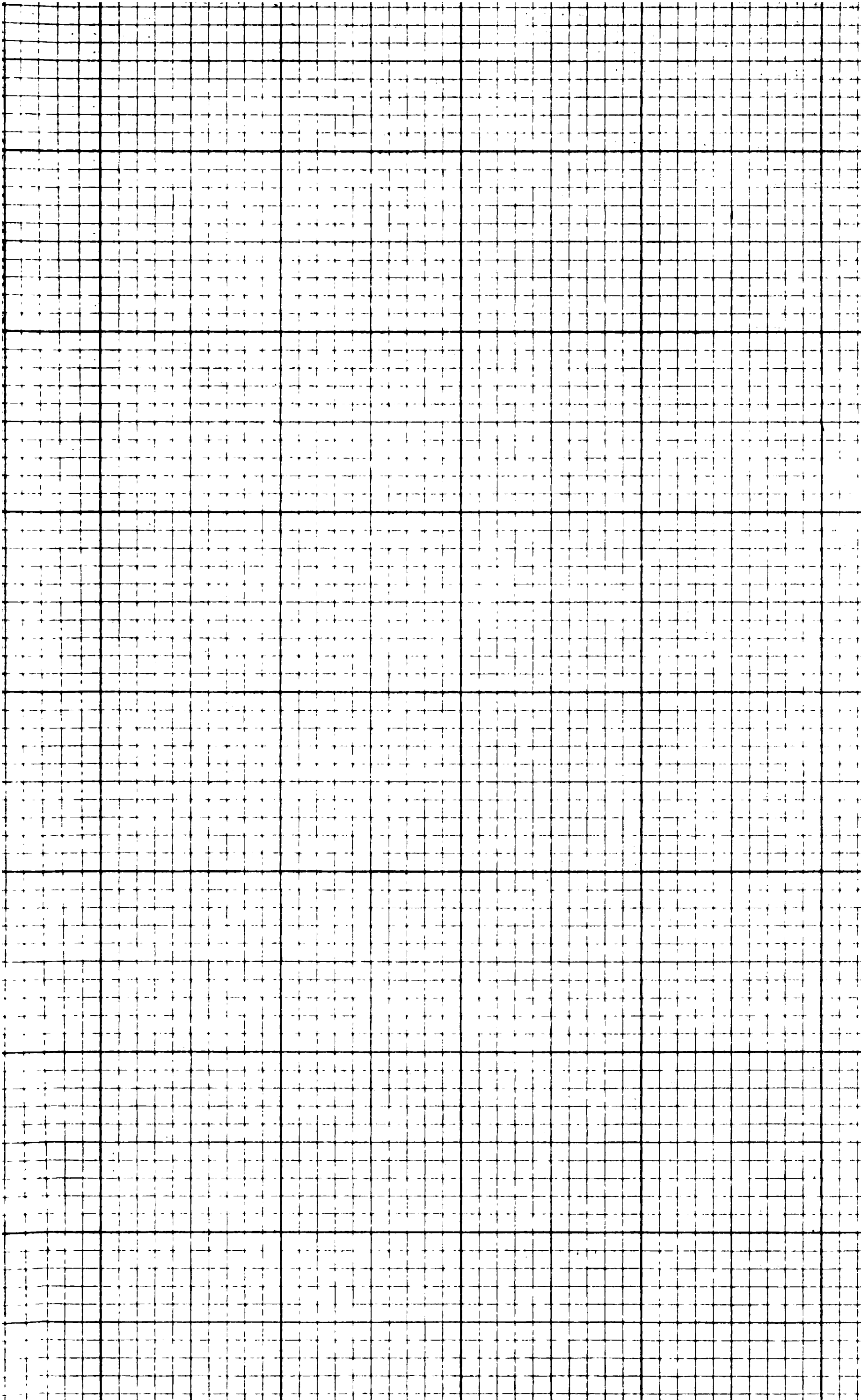

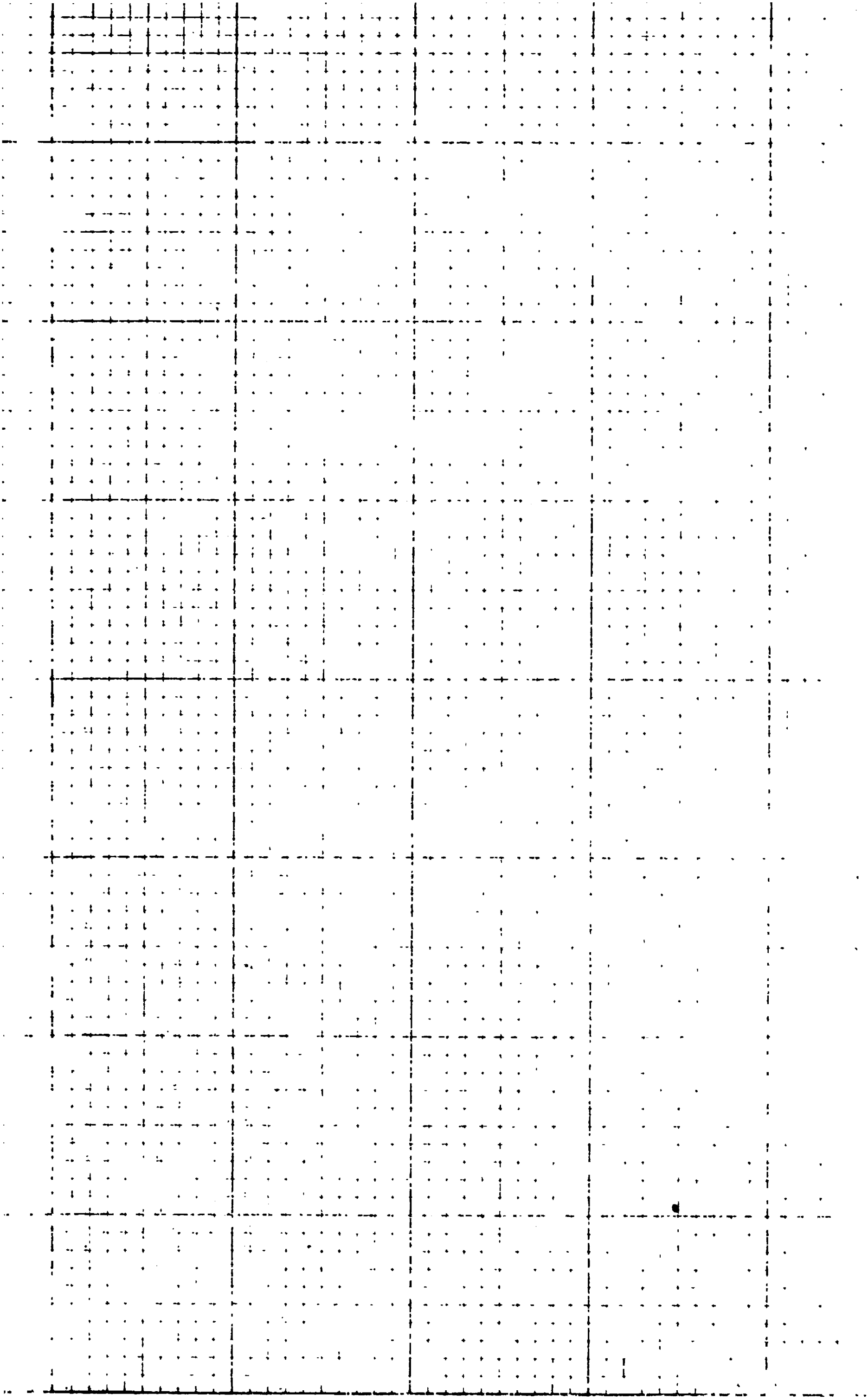

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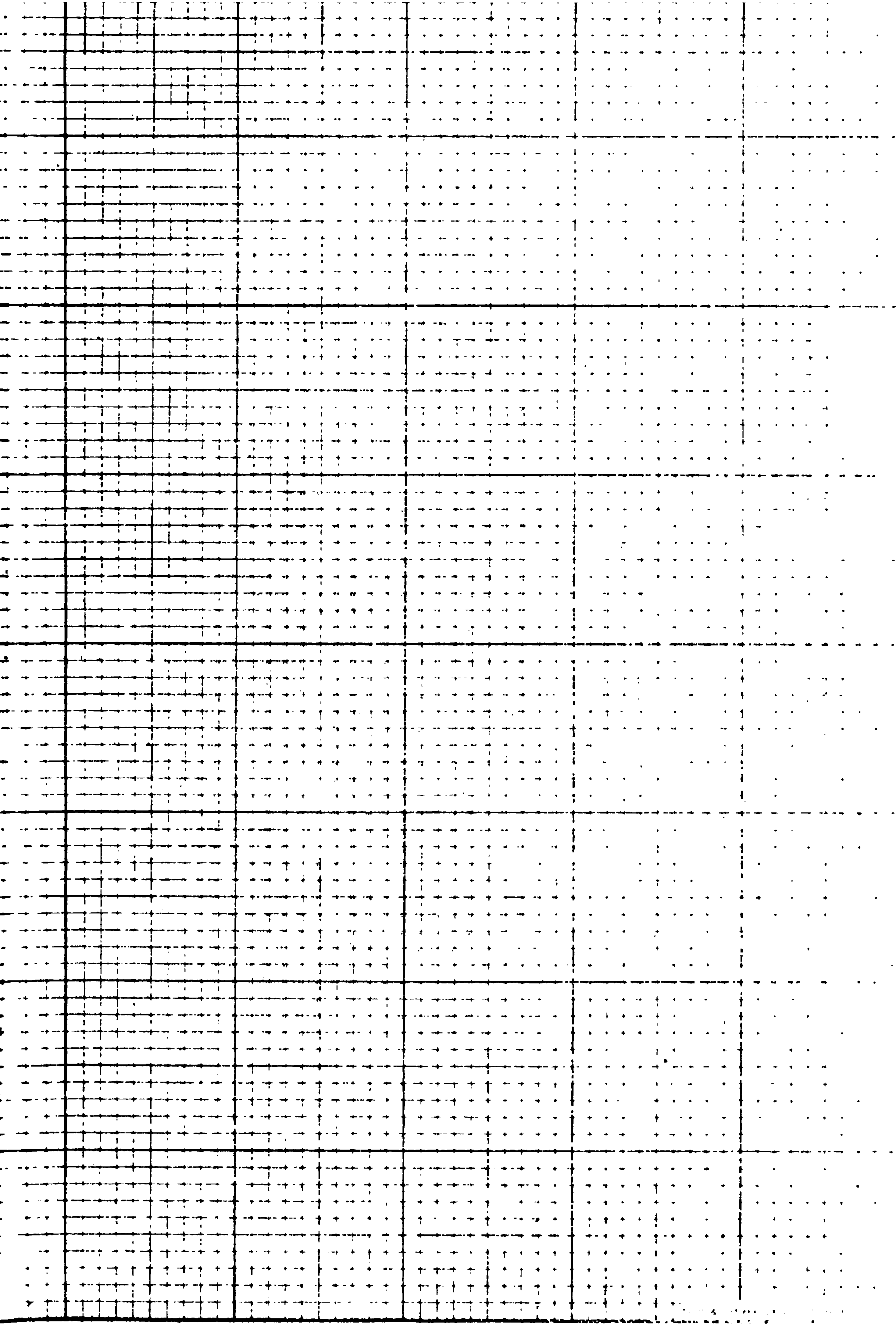

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